Material Substitution Dynamics in PV Mounting Structures

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ABSTRACT

IBIS Associates was commissioned to make an unbiased assessment of the relative economic differences of using Steel and Aluminum photovoltaic (PV) mounting structures. This assessment focused on developing an understanding of the component costs, delivery, and installation costs of structures based on both material systems along with the impact changes in materials markets might have on these economics.

Objective:

The goal of this effort has been to develop an understanding beyond just $/lb of raw material that accounts for actual component price and installed costs of different material systems in PV mounting structures.

Results:

Despite using a more expensive raw material, when properly sourced, Aluminum structures can have a lower installed cost than equivalent Steel structures. Several factors influence this cost advantage; most notably, faster installation time and reduced shipping cost relative to Steel-based PV structures.

INTRODUCTION

Aluminum extrusions have proven their value proposition in a variety of industries such as: Building and Construction, Transportation, and Engineered Products. Many of the attributes aluminum extrusions offer these industries can also be of benefit to the Solar PV Industry; these include:

- Versatility
- Lightweight
- **Strong**
- **High Strength-to-Weight Ratio**
- **Corrosion-Resistant**
- Fully Recyclable

Aluminum extrusions have been widely adopted by the PV Industry as the de facto standard for PV module frames and are commonly found as key components in both residential and commercial roof top PV mounting structures. In ground mounted PV installations, aluminum extrusions have also found a place, although to a much lesser extent than in roof-tops, as the majority of installations have given preference to galvanized Steel structures. Be that as it may, as the industry continually looks for strategies to reduce total PV system cost, developers will need to consider all of the arguments in favor of or against incorporating alternative material systems into their installations. The following paper seeks to provide a framework by which decision makers might realize the benefits associated with using aluminum extrusions in their PV mounting structures.

Why IBIS?

IBIS Associates is a management consulting firm that consults to technology-focused organizations on the manufacturing economics and competitive position of materials, processes, and products. IBIS was founded in 1987 as a spinoff from the MIT Materials Systems Lab. IBIS's specialty is to provide business development and operations solutions through the application of a set of quantitative tools, methodologies and focused techno-economic skills. IBIS Associates has unparalleled expertise in the analysis of comparative manufacturing economics, with particular depth in Steel, aluminum, and composite issues as well as photovoltaic manufacturing and installation economics. IBIS studies have been used as industry benchmarks and standards by government agencies, materials suppliers, OEMs, and trade organizations (notably the Aluminum Association).

SCOPE OF PV STRUCTURE ECONOMIC ANALYSIS

In assessing the costs of PV mounting structures, IBIS Associates first needed to define the most prevalent PV installation paradigms currently found in the marketplace. The following five systems are meant to encompass the wide range of locations and sizes that are possible:

- 5kW Residential Pitched Roof Top
- 80kw Commercial Flat Roof Top
- 1MW Utility-scale Ground Mount
- 5MW Utility-scale Ground Mount
- 50MW Utility-scale Ground Mount

While this small subset of systems is by no means exhaustive, it is sufficient for understanding how competing materials systems match up, in terms of installation economics over key market segments.

IBIS considered three main elements of cost in comparing the competitive economic position of aluminum versus galvanized Steel in these PV mounting structures. These elements included component acquisition cost, shipping costs, and mounting rack installation labor costs.

METHODOLOGY

In order to compare the costs of competing material systems in each market segment, IBIS established baseline designs for each system category. Designs were based on information collected from a variety of sources including racking component and system suppliers, solar PV integrators; as well as Engineering, Procurement & Construction companies (EPCs).

Given the prevalence of aluminum racking systems across the range of systems considered, specific part breakdowns and bills of materials were developed and acquisition costs were estimated. In addition, IBIS solicited quotes from suppliers for both aluminum and Steel designs across the range of systems being considered in order to validate component cost assumptions and price estimates.

Similarly, installation labor costs were estimated based on industry best practices and prevailing labor rates in the Southwest U.S. These assumptions were supplemented and validated by data provided by PV installers, EPCs, along with data made available by various government agencies.

Shipping costs were based on the current less-than-trailer (LTL) and full-truck-load shipping rates and the assumption of an average shipping distance of 1000 miles from fabricator to installation site.

System Designs

Residential Pitched Roof

Typical residential roof top installations consist consists of individual modules attached to a mechanical mounting system. This framework is attached to the roof's structural members. Mounting feet penetrate the roof surface and are directly attached to the roof's trusses or rafters. These penetrations require flashing to prevent the roof from leaking. The mounting rails are then attached to the feet and the PV modules are then attached to these rails.

Based on designs provided by PVsystem installers and mounting system suppliers the 5kW system requires the following components:

5.28 kW PV system

- **24 modules @ 220W_{DC}**
- **12 modules/string**
- **2 strings/array**

Installation details

- **155.4' of total rail length**
- **6 ft span between supports; 7 roof supports per rail**
- **52 module clips**

Aluminum racking systems dominate the residential roof top market. After an exhaustive search IBIS was not able to identify a single PV mounting system for residential installations made from Steel; therefore, a cost comparison of these two competing material systems was not possible for this market segment.

Commercial Flat Roof

Commercial flat roof top PV installations come in a variety of system sizes and mounting designs. The systems can be directly attached to the roof structure, similar to the residential roof top design noted above, or the racks may be ballasted with concrete blocks which keep the racks and modules in place and counteract the wind forces to which they are subjected.

The vast majority of roof top systems are "stick-built"; that is, the system is comprised of mounting feet, North-South rails, East-West rails, and legs that provide the specified tilt angle for the PV modules. The system arrives to the construction site in a bundle and installers must layout and assemble the system in its entirety. More modularized racking systems which come pre-assembled at a given tilt angle continue to be introduced to the market with varying degrees of success. These systems run the gamut of materials including aluminum, Steel and composites, but lack the design flexibility associated with the "stick-built" racking systems.

Aluminum is overwhelmingly the material of choice in these systems. It is light weight, durable, and easy to assemble. Nevertheless, a comparable Steel system was identified and a quote was provided from the supplier for comparison against the Aluminum design. Table 1 below details the key system components that make up the commercial roof top design being considered.

Table 1: Commercial Flat Roof Top Design - Aluminum

Aluminum Commercial Flat Roof Top System Components

Component (dim)	Value
N-S Array Length (ft)	102
Total N-S Beams (units)	20
Total N-S Beam Length (ft)	2046
Typical Span between Supports (ft)	6
Total Roof Connections (units)	360
Front & Back Legs Required per Array (units)	340
E-W Array Dimension (ft)	114
Total E-W Rail Length (ft)	3889
Module to Rail Connections (units)	748

Utility Scale Ground Mount Systems

Three fixed-axis ground mount systems of varying size,(i.e., 1MW, 5MW and 50MW), were considered in order to determine what affect volume might have on system economics. Ground mounted PV systems vary in design depending on geographic location and soil conditions. In some cases the mounting structure is attached to concrete foundations with front and back supporting legs, or designs call for galvanized Steel beams being pile driven into the soil. The latter is the most commonly used design for large utility scale installations and therefore the basis for comparison in this analysis. Figure 1 details examples of the two competing materials systems being considered. It is important to note that both designs call for galvanized Steel mounting posts, because aluminum posts cannot withstand the forces associated with pile driving.

Figure 1: Utility Scale Ground Mount Systems

Table 2: Utility Scale Ground Mount Systems

PV Mounting Structure Descriptions

	Aluminum Scenarios			Steel Scenarios		
	Small Ground Mount Utility	Medium Ground Mount Utility	Large Utility Ground Mount	Small Ground Mount Utility	Medium Ground Mount Utility	Large Utility Ground Mount
Array Configuration	2 x 9 Portrait	2 x 9 Portrait	2 x 9 Portrait	6 x 6 Landscape	6 x 6 Landscape	6 x 6 Landscape
Target System Size (kW)	1,000	5,000	50,000	1,000	5,000	50,000
Module Power @STC (W)	220	220	220	220	220	220
Module Length (mm)	1,660	1,660	1,660	1,660	1,660	1,660
Module Width (mm)	990	990	990	990	990	990
Target Array Size (modules)	4,546	22,728	227,273	4,546	22,728	227,273
Modules per String	18	18	18	18	18	18
Strings per Array	253	1,263	12,626	253	1,263	12,626
Actual System Size (modules)	4,554	22,734	227,268	4,554	22,734	227,268
Array Capacity (kW) [Calculated]	1,002	5,001	49,999	1,002	5,001	49,999

Table 2 details the design characteristics of the competing material systems for the three installation sizes being analyzed. For the Aluminum mounting system, IBIS collected data from system suppliers to build up a bill of materials for each system and estimate their respective costs; whereas, for the Steel designs the system supplier provided an overall cost estimate for the system in total. A detailed cost breakdown of the Steel system components was not provided.

Cost Analysis

System Component Costs

Upon developing the each structure's bill of materials, collecting component pricing data as well as collecting system quotes for comparable Steel structures, it was possible to compare the acquisition costs over the range of installation locations being considered. It can be seen from Table 3 below that although Aluminum is a more expensive material on a per pound basis that its overall cost is comparable to that of the Steel systems. In commercial flat roof top applications Aluminum proves to be significantly less expensive that the Steel design.

Table 3: System Acquitison Cost Estimates

	Pitched Residential Roof Top	Commercial Flat Roof Top		Small Ground Mount Utility		Medium Ground Mount Utility		Large Utility Ground Mount	
Scenario	Aluminum	Aluminum	Steel	Aluminum	Steel	Aluminum	Steel	Aluminum	Steel
Component List Price Total	$2,377	$39,187	$43,200	$394,921	$330,000	$303,404	$290,000	$271,226	$270,000
Discounted Price Total*	$2,377	$33,309		$335,682					
System Size (kW)	5	80	80	1000	1000	5000	5000	50000	50000
System Price $/W	$0.48	$0.42	$0.54	$0.34	$0.33	$0.30	$0.29	$0.27	$0.27

** List pricing discounted by 15%*

Installation Costs

Installation costs were based on data collected from EPCs, PV system installers and supplemented with data from government agencies[1]. Table 4 below details the installation costs that IBIS was able to compile. These costs are fully burdened labor costs based on a labor rate of $33 per hour and also include installer profit. Not included in these costs are site preparation and permitting which are expected to remain constant regardless of material system.

[1] **Residential, Commercial, and Utility-Scale Photovoltaic (PV) System Prices in the United States: Current Drivers and Cost-Reduction Opportunities.; Goodrich, A. C.; Woodhouse, M.; James, T.; NREL Research Report 2012**

Table 4: System Installation Costs

	Pitched Residential Roof Top	Commercial Flat Roof Top		Small Ground Mount Utility		Medium Ground Mount Utility		Large Utility Ground Mount	
Scenario	Aluminum	Aluminum	Steel	Aluminum	Steel	Aluminum	Steel	Aluminum	Steel
Total Labor ($/W)	$0.61	$0.06	$0.07	$0.02	$0.03	$0.02	$0.04	$0.01	$0.03

As indicated by the labor costs listed above, Aluminum has a clear advantage over the Steel designs with respect to installation efficiency. Lightweight aluminum components, with their ease of assembly, can result in labor savings of between 19% to 60% on a per Watt basis.

Shipping Costs

Shipping cost estimates were based on a 1000 mile delivery distance from system manufacturer to the construction site. Shipping costs for the smaller systems were based on less-than-truckload (LTL) quotes provided by Conway Freight, whereas, the larger system sizes shipping costs were based on full trailer loads shipped at a rate of $3.87 per mile.

Table 5: System Shipping Costs

	Pitched Residential Roof Top	Commercial Flat Roof Top		Small Ground Mount Utility		Medium Ground Mount Utility		Large Utility Ground Mount	
Scenario	Aluminum	Aluminum	Steel	Aluminum	Steel	Aluminum	Steel	Aluminum	Steel
kW	5	80	80	1000	1000	5000	5000	50000	50000
Estimated lbs	187	4,309		44,344	127,348	221,700		2,217,000	
Actual lbs			28,000		137,533		684,417		6,835,683
Truck loads	LTL	LTL	LTL	1	3	5	15	50	152
Shipping Cost Quote	$252	$2,365	$3,091	$4,004	$12,025	$20,020	$61,598	$200,199	$615,211
Shipping Cost ($/W)	**$0.050**	**$0.030**	**$0.039**	**$0.004**	**$0.012**	**$0.004**	**$0.012**	**$0.004**	**$0.012**

As shown in the table above, the Aluminum systems are less expensive to ship than their Steel counterparts in every case. Although the Aluminum systems are constrained by their volume before mass, shipping the Aluminum systems costs 23% to 66% less than comparable Steel designs.

Cost Summary

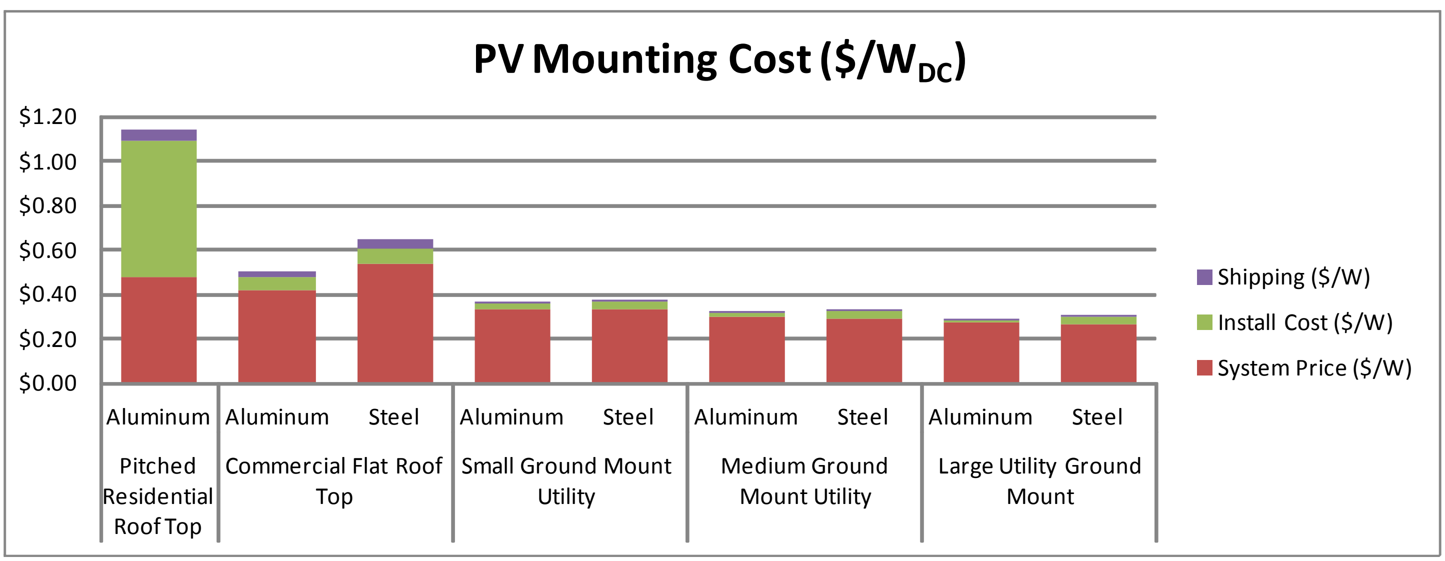

Figure 2: System Cost Summary

Taking into account the three areas of cost considered in this analysis, it can be seen that PV mounting structures made from Aluminum extrusions are cost competitive with their Steel counterparts. While the advantage Aluminum has over Steel appears to be most compelling in Commercial Roof Top installations, there are clear reasons to consider Aluminum extrusions for even the largest Ground Mount Utility Scale installations. Overwhelmingly acquisition costs dominate system economics; however, the significant savings related to installation and shipping costs relative to Steel make Aluminum an ideal choice over the range of system sizes considered.

Recycling Value

Aluminum is inherently more recyclable than galvanized Steel. This fact is reflected in the differential between the cost of the primary metal versus its scrap value. Using the large scale ground mount system as a basis for comparison IBIS compared the residual value of the Aluminum structure to that of its Galvanized Steel counterpart. Based on the US Geological Surveys published scrap value for each metal respectively it can be seen that the Aluminum structure is worth three times that of the Steel system upon decommissioning.

Table 6: Comparison of Recycling Value

50 Mega Watt System

	Aluminum	Steel
Total Mass of Structure (lbs)	2,473,348	6,835,683
Scrap Price ($/lb)*	$0.79	$0.09
Total Recycled Value	$1,961,365	$635,719

**USGS Minerals Yearbook 2009 - Recycling Statisitcs*

CONCLUSIONS

Aluminum extrusions are an excellent material technology choice for PV mounting structures. They are lightweight, easy to assemble and offer significant performance benefits over galvanized Steel structures.

Clearly, techno-economic studies like this will be somewhat case specific, and a range of cost numbers should be expected. However, the overall outcome/approach would seem to be valid for similar equivalent structure designs.

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